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OSCAR PHASE 1B PROGRAM REVIEW.(U)

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LEVEL II

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GTE Systems

OSCAR PHASE IB

GTE SYLVANIA

PROGRAM REVIEW

FEBRUARY 18, 1981

Contract N00039-79-C-0379

Sylvania Systems Group
Western Division

(6) OSCAR PHASE IB GTE Systems

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AGENDA

- INTRODUCTION
- BEAM SHAPER PROGRESS; and
- SYSTEMS ANALYSIS.

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INTRODUCTION

- JULY 1980 DIRECTIONS:
  - (1) SUSPEND SHAPER, SWITCH AND SCANNER WORK UNTIL THEIR GENERAL APPLICABILITY IS ASSURED
  - (2) SYSTEM ANALYSIS
    - REQUIREMENTS RELIEF (TIME, AREA)
    - CONSIDER TECHNOLOGY LIMITATIONS
    - CONSIDER OPERATION FROM LOWER ORBITS
    - ADOPT AND IMPLEMENT NOSC PROPAGATION MODEL
    - CONSIDER BUOY MOUNTED RECEIVERS

BEAM SHAPER PROGRESS

- SYSTEM LEVEL REQUIREMENTS
- BEAM SHAPER APPROACH
- RECENT BEAM SHAPER PROGRESS

BEAM SCANNING AND SWITCHING FOR LOW EARTH ORBITS

ORBIT	ANGULAR SCAN EXTENT EQUATOR	60° N	NUMBER OF SPOTS	SINGLE SCAN TIME (SEC)
A	±72.23°	±64.06°	37	8.88
B	±41.4°	±26.02°	49	12.25

- DEAD TIME BETWEEN FRAMES: 0 to 4.88 MILLISECONDS
- RASTER SCAN, NOT RANDOM:
  - (a) "RAPID" BUT NEARLY CONTINUOUS SCANNING
  - (b) NO SWITCH REQUIRED
  - (c) RAPID BUT NEARLY CONTINUOUS SHAPING
- ONLY THE SHAPER HAS A COMMON RANGE OF REQUIREMENTS WITH THE HIGHER ORBIT DEVICES

BEAM SHAPING REQUIREMENTS

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REQUIREMENT	MOLNIYA	5 X SYNC	LOW EARTH ORBITS "A"	LOW EARTH ORBITS "B"
OUTPUT BEAM DIVERGENCE	1-20 millirad	0.2-4 millirad	3^0-14.2^0 ++	1.57^0-2.37^0 ++
MAX ANAMORPHIC RATIO (1 AXIS EXPANSION)	X4 $(\cos 75.5^0)^{-1}$	X3 $(\cos 70.5^0)^{-1}$	X8 $(\cos 83^0)^{-1}$ X3.3 $(\cos 72^0)^{-1}$	X1.84 $(\cos 57^0)^{-1}$ X1.2 $(\cos 34^0)^{-1}$
TIME BETWEEN SPOTS +	~1 msec	~1 msec	~5 millisec (Continuous)	~5 millisec (Continuous)
INPUT BEAM SIZE	~ 5 cm DIAMETER	~5 cm DIAMETER	~5 cm DIA	~5 cm DIA
INPUT BEAM QUALITY	~ 10-20 X DIFF LIMIT	~10-20 X DIFF LIMIT	~10-20 X DIFF LIMIT	~10-20 X DIFF LIMIT

+MIGHT REQUIRE MULTIPLE OUTPUT OPTICAL CHAINS

++ASSUMES SQUARE EQUAL-AREA SPOTS ACROSS THE SCAN

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SPECIFICATIONS FOR BRASSBOARD SHAPING UNIT

INPUT BEAM SIZE: 50 mm DIAMETER

INPUT BEAM DIVERGENCE: $< 200\ \mu$RAD

OPERATING WAVELENGTH: 532 nm

OUTPUT BEAM SIZE: ≈ 50 mm DIAMETER

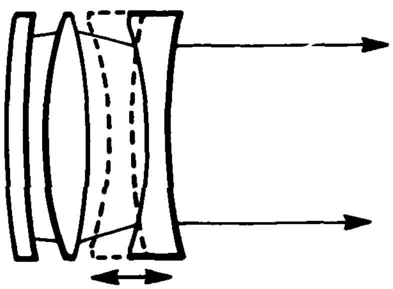
OUTPUT DIVERGENCE RANGE: 250 μRAD TO 50 mRAD, CONTINUOUS

OUTPUT ASPECT RATIO: SYMMETRIC TO 4:1 ANAMORPHIC (CONTINUOUS)

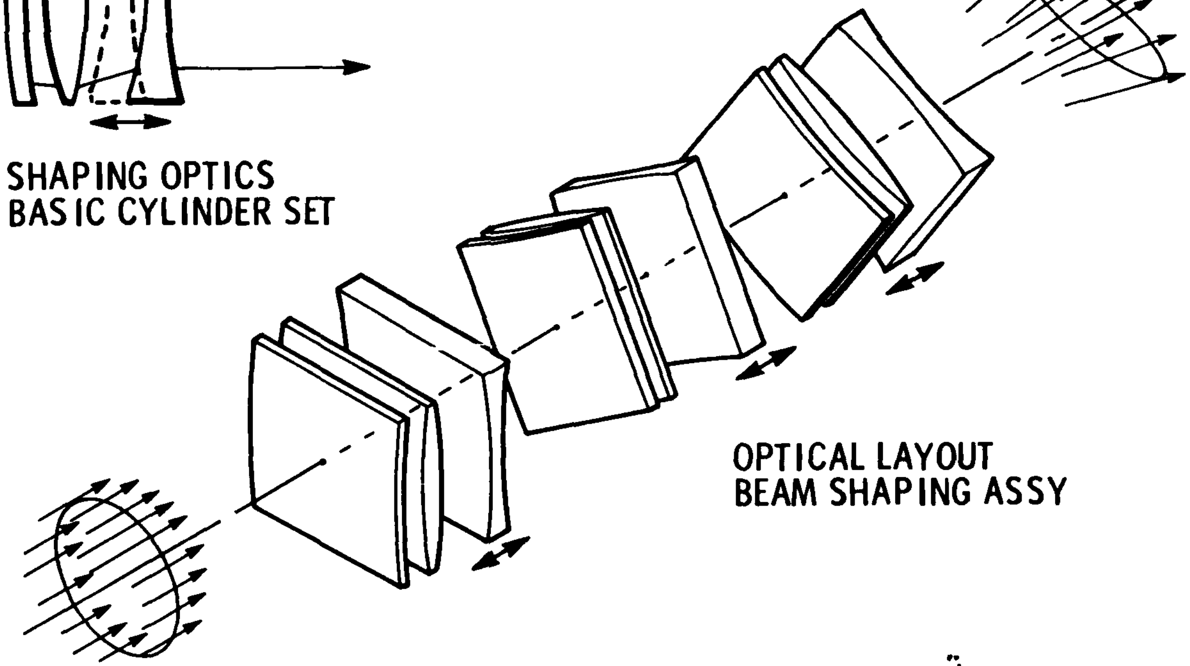
ORIENTATION OF ANAMORPHIC AXIS: 0^{0} TO 180^{0}, CONTINUOUS

ALL MOTIONS LINEAR (NO ROTATIONS)

BEAM SHAPING OPTICS - OPTICAL ISOMETRIC



SHAPING OPTICS
BASIC CYLINDER SET



OPTICAL LAYOUT
BEAM SHAPING ASSY

BEAM SHAPING OPTICS - THEORETICAL PERFORMANCE SUMMARY

MINIMUM OUTPUT DIVERGENCE: $< 250\ \mu$RAD

MAXIMUM OUTPUT DIVERGENCE: >50 mRAD

RATE OF CHANGE (SYMMETRIC): 8.0 mRAD/mm LENS MOTION

FULL RANGE OF ELEMENT MOTIONS: ≈ 7 mm

MAXIMUM ANAMORPHIC RATIO: $> 4/1$

ANAMORPHIC ORIENTATION: 0 TO 180^0

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BEAM SHAPING OPTICS - CONTROL EQUATION

- DEFINITIONS

  "AVERAGE DIVERGENCE" = (MAX + MIN)/2 = ϕ_{AVG}

  "EXTRA DIVERGENCE" = MAX - AVG = AVG - MIN = ϕ_{EXT}

  (ANAMORPHIC RATIO = MAX/MIN)

- INPUTS

  ϕ AVG

  ϕ EXT

  $\bar{\theta}$ (ORIENTATION OF MAJOR AXIS)

- OUTPUTS

  DIVERGENCE, 1st GROUP = $D_0 = 2/3\ \phi_{AVG} - 4/3\ \phi_{EXT} \cos 2\bar{\theta}$

  DIVERGENCE, 2nd GROUP = $D_{60} = 2/3\ \phi_{AVG} + 2/3\ \phi_{EXT} (\cos 2\bar{\theta} - \sqrt{3} \sin 2\bar{\theta})$

  DIVERGENCE, 3rd GROUP = $D_{120} = 2/3\ \phi_{AVG} + 2/3\ \phi_{EXT} (\cos 2\bar{\theta} + \sqrt{3} \sin 2\bar{\theta})$

- LENSES REPOSITIONED FROM MOTION EQUATION (8 mRAD/mm)

BEAM SHAPING OPTICS - SENSITIVITY SUMMARY (AT MINIMUM DIVERGENCE)

DYNAMIC

- AXIAL MOTION REPEATABILITY $\pm 6\,\mu m$ ($\pm 50\,\mu RAD$)

CONSTRUCTION AND STATIC PARAMETERS ANALYSED:

- RADII OF CYLINDRICAL CURVATURE
- THICKNESS / AIRSPACE
- ELEMENT WEDGE
- ELEMENT TILT
- SURFACE SKEW
- ELEMENT CENTERING
- ELEMENT SKEW

SUMMARY: TOLERANCES ARE IN "PRECISION" CLASS

SYSTEM MAY REQUIRE SOME "TUNING" AT ASSEMBLY

BEAM SHAPING OPTICS
MECHANICAL APPROACH

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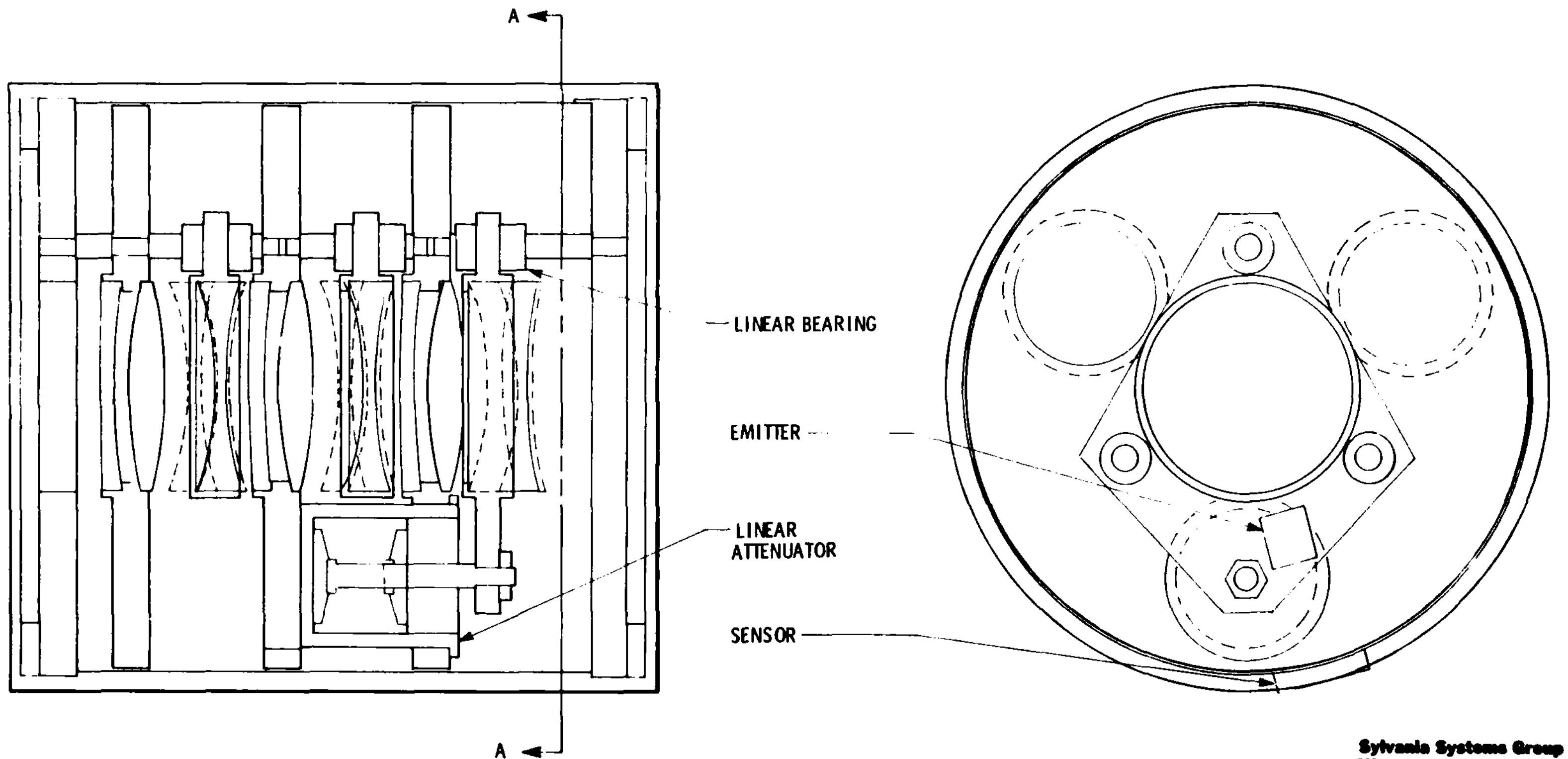
- MOTOR -- LINEAR BRUSHLESS DC TORQUE MOTORS
- POSITION FEEDBACK -- LENS MOUNTED LED FOCUSED EMITTERS WITH FRAME MOUNTED POSITION SENSING DETECTORS.



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BEAM SHAPING UNIT NEAR TERM PLANS

- PREPARE LENS DRAWINGS AND ORDER
- BREADBOARD MOTOR / POSITION CONTROL CIRCUIT
- PREPARE FINAL MECHANICAL DESIGN
- ESTABLISH PERFORMANCE EVALUATION PROCEDURES (INCLUDING COMMAND GENERATION APPROACH)
- DEVELOP SCORING SYSTEM

AGENDA

- INTRODUCTION
- BEAM SHAPER PROGRESS
- SYSTEMS ANALYSIS

SYSTEMS ANALYSIS

- NEAR EARTH ORBIT ANALYSIS
- CONTINUING HIGHER ORBIT ANALYSIS
- NAVY PROPAGATION MODEL REVISIONS AND RELATED TOPICS
- DEPTH NOMOGRAPH I

NEAR EARTH ORBIT ANALYSIS

- ORBITS
- COVERAGE APPROACH
- NUMBER OF SATELLITES
- SCANNING CONSIDERATIONS
- SYSTEM TRADEOFF EQUATIONS
- MESSAGE DESIGN AND REMOTE SENSOR IMPACT
- SYNCHRONIZATION
- LAUNCH VEHICLE AND SPACECRAFT SIZING
- SCALING OF ALLOWABLE PROPAGATION PATH LOSS

PREVIOUS LOW ORBIT ANALYSIS

- FULL TEMPORAL REQUIREMENT
- MAXIMUM ALLOWABLE ZENITH ANGLE $\leq 45^0$
- RESULT: 100 SATELLITES REQUIRED

ORBITS

- FIRST ORDER ANALYSIS
- CIRCULAR POLAR - a) NEARLY FIXED SCAN RATE
  b) LATITUDE DEPENDENT AREA
  c) EASY TO VISUALIZE
- ELLIPTICAL?
- TWO GENERIC ORBITS:

NAME	PERIOD (HRS)	ALTITUDE km	ALTITUDE mi	ALTITUDE nmi	NUMBER OF TRACKS/24 HRS
A	1.5 (90 MIN)	281	175	151.6	16
B	2.0 (120 MIN)	1688	1049	910.9	12

COVERAGE APPROACH

- EACH ORBIT COVERS A SWATH EQUAL TO THE DISPLACEMENT OF ITS GROUND TRACK

ORBIT	DISPLACEMENT
A	2502 km
B	3336 km

- ZENITH ANGLES EXCEED THE PREVIOUS MAXIMUM OF 45^0

	ZENITH ANGLE AT SWATH EDGE	
ORBIT	AT EQUATOR	AT 60^0 N
A	81.8^0	69.2^0
B	55.9^0	33.3^0

NUMBER OF SATELLITES

- FRACTION OF EARTH COVERED $\frac{\text{2 X SWATH WIDTH}}{\text{CIRCUMFERENCE}}$

ORBIT	FRACTION OF EARTH COVERED
A	1/8
B	1/6

- T = REQUIRED COVERAGE TIME
- NUMBER OF SATELLITES = $\left[\left(\frac{T}{\text{PERIOD}}\right)(\text{FRACTION COVERED PER ORBIT})\right]^{-1}$

NUMBER OF SATELLITES II

	NUMBER OF SATELLITES REQUIRED	
T (HRS)	A	B
12	1	1
8	2	2
6	2	2
4	4	3
2	-	6
1.5	8	-

- GENERAL RESULT:

$$\text{NUMBER OF SATELLITES REQUIRED} \approx \frac{12}{T(HRS)}$$

SCANNING CONSIDERATIONS

- SCAN SPEED ALONG TRACK = SPEED OF SUB-SATELLITE POINT ALONG GROUND TRACK

A	7.41 km/SEC
B	5.56 km/SEC

- SPOT SCAN ACROSS SWATH:

SQUARE SPOTS ⟶ $N_{SPOTS} = \frac{\text{SWATH WIDTH}}{D_S}$

$T_{SWATH} = (N_{SPOTS})(M_W)$

- DURING T_{SWATH}, SUB-SATELLITE POINT MOVES $D_S = (T_{SWATH})$(SPEED ON EARTH'S SURFACE)

$$\longrightarrow M_W = \frac{D_S^2}{(\text{SWATH WIDTH})(\text{SPEED ON EARTH'S SURFACE})} = \frac{D_S^2}{18{,}800\ (\text{km}^2)}$$

SCANNING CONSIDERATIONS II

ORBIT	D_S (km)	M_W (SEC)
A OR B	40	0.083
	60	0.192
	100	0.532

SPOT PARAMETERS:

	ANGULAR DIAMETER (AT NADIR)		N_{SPOTS}	
D_S (km)	A	B	A	B
40	8.16^0	1.36^0	64	85
60	12.26^0	2.04^0	43	57
100	20.5^0	3.4^0	26	34

SYSTEM TRADEOFF EQUATIONS

- DIFFERENT SCAN APPROACH $\rightarrow \ell$ DEPENDENCE?
- $\frac{S}{N} \alpha \frac{E_p}{A_{SPOT}}$
- PPM: $E_p = \frac{P_{AV}}{PRF} \approx P_{AV} (2 \ell t_s)$
- $A_{SPOT} = \frac{A_{SWATH}}{N_{SPOTS}}$
- SQUARE SPOTS $\rightarrow A_{SPOT} = (L_{SWATH})(V_{SAT}) M_W \quad (18,800 \text{ km}^2) M_W$
- $M_W \simeq \frac{M_L}{\ell} \quad 2 \ell t_s$

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SYSTEM TRADEOFF EQUATIONS II

$$\frac{S}{N} \quad \alpha \quad \frac{E_p}{A_{SPOT}} \quad \alpha \quad \frac{P_{AV}\,\ell}{M_L\ (18,800\ \mathrm{km}^2)}$$

MESSAGE DESIGN

- $2^{\ell} t_s + t_f = \frac{1}{\overline{PRF}}$
- STANDARD t_s AND $\overline{PRF}$ $\Longrightarrow$ $\ell = 8$, $t_f = 4.88\ (10^{-3})$ SECONDS
- EAM $\Longrightarrow$ $M_W = 0.25$ SECONDS

  $A_{SPOT} = 4700\ km^2$

  $D_{SPOT} = 69\ km$

ORBIT	N_{SPOTS}	SCAN TIME (SECONDS)
A	37	8.88
B	49	12.25

REMOTE SENSOR

- I: REMOTE SENSOR PREDICTS WIDE PULSE CONDITIONS

  $\Rightarrow$ GO TO $\ell = 4$, $\overset{4}{2}t_s$, DOUBLE DWELL TIME IN THOSE AREAS

- II: NO REMOTE SENSOR INFORMATION AVAILABLE

$$t_s \Rightarrow 6t_s \Rightarrow \begin{array}{l} \ell = 6 \\ M_W = 0.34 \text{ SECONDS} \\ D_{SPOT} = 80 \text{ km} \end{array}$$

ORBIT	N_{SPOTS}	SCAN TIME (SECONDS)
A	32	10.88
B	42	14.28

- DEGRADATION: AREA $\left(\frac{69}{80}\right)^2 = 0.74 \Longleftrightarrow \ell: \frac{6}{8} = 0.75$

AVERAGE SPOT SIZE

- GOOD REMOTE SENSOR: $[60\ \text{km}]^2$ AVERAGE SPOT AREA
- MOLNIYA - SINGLE SATELLITE IN PACIFIC: $\bar{A}_{SPOT} = [141.4\ \text{km}]^2$
  - TWO SATELLITES IN ATLANTIC: $\bar{A}_{SPOT} = [71.5\ \text{km}]^2$
- FOR SAME TECHNOLOGY, LOW EARTH ORBIT PROVIDES BETTER <u>AVERAGE</u> AVAILABILITY, OR, LOW EARTH ORBIT PROVIDES THE SAME <u>AVERAGE</u> AVAILABILITY FOR LOWER TECHNOLOGY (SMALLER SATELLITE)

LAUNCH VEHICLE AND SPACECRAFT SIZING

	LOW ORBIT (OPERATIONAL)	HIGH ORBIT (OPERATIONAL)
POWER REQUIRED	25 kW	25 kW
SATELLITE SIZE		
LASER COMM	2400 lbs	2400 lbs
SOLAR ARRAY	1560 at 4.6K FT^2	860 at 256 FT^2
HEAT DISSIP	800 at 310 FT^2	775 at 540 FT^2
POWER COND	500	1530
C^3	300	300
GNC	140	140
ATTITUDE CONTROL	0	750
INTERSTAGE STRUCTURE	1500	1400
BATTERIES	2734	0
TOTAL	9934 at 4.6 FT^2	8155 at 540 FT^2
ORBIT ALTITUDE	500 nmi	25,000/400
INCLINATION	70^{o+}	63^0
PERIOD	~105 min	12 HR
MIN LIFE	5 YEAR	5 YEAR
LAUNCH SITE	VAFB	KSC
BOOSTERS	SHUTTLE (3 oms KITS) TITAN IIIC	SH + 3-STAGE IUS TITAN-CENTAUR

BATTERIES AND ORBITAL LIFE

	NiCd	NiH_2
SPECIFIC CAPACITY	10 W/lb	25 W/lb
DEPTH OF DISCHARGE	20%	60%
CYCLE LIFE	20,000	>5,000

ALTITUDE	LIFE
350 nmi	0.4 YEARS
440 nmi	4 YEARS
500 nmi	20 YEARS

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SOLAR CELL TECHNOLOGY

	SILICON	GaAs
SPECIFIC CAPACITY		
BY WEIGHT	50 W/lb	50 W/lb
BY AREA	11 W/SQ FT	17 W/SQ FT
COST	$10/CELL	$20/CELL
EFFICIENCY	11%	17%
RADIATION DEGRADATION/YEAR	55%/YEAR	5%/YEAR
TEMPERATURE DEGRADATION	0.5%/°C	0.25%/°C
FLOWN	YES	YES
AVAILABILITY		
NOW	YES	NO
DURING 1980's	YES	YES

SCALING OF ALLOWABLE PATH LOSS

- BIOLUMINESCENT LIMITED OPERATION: OLD STRENGTH

$$1\ \text{Å}/\text{IM}^2 \Longrightarrow P_{BL} = 4\,(10^{-9})\ \text{WATTS}$$

$$NEP_B = 6.55\,(10^{-14})(\Delta t)^{-1/2}\ \text{WATTS}$$

$$SNR_{REQ} \geq 8;\ A_{SPOT} = [80\ \text{km}]^2;\ E_p = 2\ \text{JOULES}$$

$$\boxed{\frac{\tau_a\,\tau_c\,\tau_{cw}\,\tau_{aw}\,\tau_w}{[\Delta t]^{1/2}} \geq 9.86\,(10^{-3})\ (\text{SEC})^{-1/2}}$$

SCALING II

- $\Delta t = 10^{-7}\ \tau$

THICK CLOUD $\Longrightarrow$ $\tau_{cw} = 1,\ \tau_{aw} = 0.8;\ \tau_a = 0.6$

$$\boxed{\begin{array}{l} \dfrac{\tau_c\ \tau_w}{\tau^{1/2}} \geq 6.49\,(10^{-6}) \\[2ex] 10 \log_{10}\left(\dfrac{\tau_c\ \tau_w}{\tau^{1/2}}\right) \geq -51.9\ \text{dB} \end{array}}$$

SCALING III

- $\frac{\tau_c \tau_w}{\tau^{1/2}} \propto \left(\frac{1}{E_p}\right) (B_{OPT})^{1/2} \left(\frac{1}{d}\right) (A_{SPOT})$
- 0.3 m/3 Å $\Longrightarrow \frac{\tau_c \tau_w}{\tau^{1/2}} \geq 4.23\,(10^{-5}) \longrightarrow -43.7$ dB

  [51.9 dB]
- BEST CASE: $\tau_c = \tau = 1$; 1 B WATER AND BLUE LIGHT

  1m^2/1 Å $\longrightarrow$ 362 m (1188 FT)

  0.3 m/3 Å $\longrightarrow$ 305 m (1001 FT)

SCALING IV: DAYTIME COVERAGE

- SAME $\hat{P}_R$
- SOLAR LIMITED: $P_B = 4.8\,(10^{-2})\,(\tau_a\,\tau_c\,\tau_{cw}\,\tau_{aw}\,\tau_w)$

$$NEP_B = 2.257\,(10^{-10})\,\left[\frac{\tau_a\,\tau_c\,\tau_{cw}\,\tau_{aw}\,\tau_w\,\tau_{aw}}{\Delta t}\right]^{1/2}$$

- $\dfrac{\tau_{SIG}}{[\tau_{SUN}]^{1/2}}\;\dfrac{1}{(\Delta t)^{1/2}} \geq 34.0$
- $\Delta t = 10^{-7}\tau;\quad \tau_c = 0.6;\quad \tau_{aw} = 0.8;\quad \tau_{cw} = 1$

$$\boxed{\frac{\tau_c^{\,s}\;\tau_w^{\,s}}{[\tau_c^{\,su}\;\tau_w^{\,su}]^{1/2}}\;\frac{1}{\tau^{1/2}} \geq 1.55\,(10^{-2})}$$

DAYTIME COVERAGE II

- THICK CLOUDS:

$$\tau_W{}^S = \tau_W{}^{SU}$$

$$\tau^S{}_C(\theta_S) \approx \tau_C(o)\,(\cos\theta_S)^{1/2}$$

$$\tau^{SU}{}_C\,(\theta_{SU}) \approx \tau_C\,(o)\,(\cos\theta_{SU})^{3/2}$$

$$\frac{[\tau_C(o)]^{1/2}\;[\tau_W]^{1/2}}{\tau^{1/2}}\;\frac{[\cos\theta_S]^{1/2}}{[\cos\theta_{SU}]^{3/2}} \geq 1.55\,(10^{-2})$$

- τ_{OPT} 50; $\tau_c\,(o) = 0.17$; $s\,t = 10\,\mu$seconds, $\theta_S = 45^0$

θ_{SU}	$k(m^{-1})$	DEPTH (m)
0	0.033	48.7
20	0.033	54.4
	0.062	30
40	0.062	38.8
	0.116	20.8

SYSTEMS ANALYSIS

- NEAR EARTH ORBIT ANALYSIS
- CONTINUING HIGHER ORBIT ANALYSIS
- NAVY PROPAGATION MODEL REVISIONS AND RELATED TOPICS
- DEPTH NOMOGRAPH I.

HIGHER ORBIT ANALYSIS

- ANAMORPHIC CORRECTION IMPACT
- RANDOM SCAN "COST"
- CORRECTION TO REQUIRED SNR
- SPOT SHAPE, SPOT PATTERN CONSIDERATIONS
- ADDITIONAL DCM RUNS

ANAMORPHIC CORRECTION IMPACT

- CIRCLES, NOT ELLIPSES
- SINGLE PULSE SNR IMPACT - $\cos \phi_s$
- SYSTEM IMPACT - MAXIMUM ϕ_s
  DISTRIBUTION OF ϕ_s

ANAMORPHIC II

- SAMPLE DISTRIBUTIONS:

"UNIFORM" $P(\phi_s) = \dfrac{1}{\phi_M}$

PEAKED AT LOW ANGLES: $P(\phi_s) = \dfrac{\cos\phi_s}{\sin\phi_M}$ (MOLNIYA)

PEAKED AT LARGE ANGLES: $P(\phi_s) = \dfrac{\sin\phi_s}{1-\cos\phi_M}$ (GEOSTAT)

$$\overline{Ep} = \left[\int_0^{\phi_M} \cos\phi_s \, P(\phi_s)\, d\phi_s\right]^{-1} = \begin{cases} \left[\dfrac{\sin\phi_M}{\phi_M}\right]^{-1} & ;\ \text{UNIFORM} \\ \left(1/2\left[\cos\phi_M + \dfrac{\phi_M}{\sin\phi_M}\right]\right)^{-1} & ;\ \text{PEAKED LOW} \\ \left(1/2\left[\dfrac{\sin^2\phi_M}{1-\cos\phi_M}\right]\right)^{-1} & ;\ \text{PEAKED HIGH} \end{cases}$$

ANAMORPHIC III

	$\overline{E_p}$		
$P(\phi s)$	ϕ_M 60^0	ϕ_M 70^0	ϕ_M 73^0
UNIFORM	1.21/0.8 dB	1.30/1.14 dB	1.33/1.25 dB
PEAKED AT 0	1.18/0.7 dB	1.22/0.85 dB	1.23/0.91 dB
PEAKED AT ϕ_M	1.33/1.25 dB	1.50/1.74 dB	1.55/1.9 dB

- PROBABLY A 1.5 dB TO 3 dB IMPACT
- RETAIN ANAMORPHIC CORRECTION

RANDOM SCAN "COST"

- PERFORMANCE
- COMPLEXITY/COST
- RISK

RANDOM SCAN PERFORMANCE

- SINGLE PULSE SNR - UNAFFECTED
- DEAD TIME BETWEEN MESSAGES -

  0, FOR (BASELINE) TWO OPTICAL TRANSMITTER HEADS
- SPOT OVERLAP - FRACTION OF ILLUMINATED SPOT "COUNTED" AS COVERED

  CIRCULAR SPOTS - (A) SQUARE IN CIRCLE → 0.6366
  (B) STAGGERED SQUARES/CIRCLES → 0.815
  } RANDOM & RASTER

  SQUARE SPOTS - RANDOM ⇒ 0.7225 FOR SMALLEST SPOT, DUE TO SUBMARINE ESCAPE

  RASTER ⇒ ~ 1.0
- FOR SQUARE SPOTS, AREA COVERAGE RATE ~ 38% FASTER WITH RASTER SCAN; ≈ 1% TO 2% IN AVAILABILITY

RANDOM SCAN COMPLEXITY AND RISK

- THREE AREAS:
  - (1) TWO OPTICAL TRANSMITTER CHAINS
  - (2) "DISJUNCT" SHAPER SETTINGS (VERSUS "CONTINUOUS" VARIATION)
  - (3) POINTER REPEATABILITY

  (1) REDUNDANCY $\Rightarrow$ TWO CHAINS PRESENT

  (2) TWO CHAINS MAKES "DISJUNCT" SETTINGS FEASIBLE

  (3) RANDOM POINTER APPEARS FEASIBLE
- NEGLIGIBLE "COST" DIFFERENCE

CORRECTION TO REQUIRED SIGNAL-TO-NOISE RATIO

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- PREVIOUS EXPRESSION: (BOUND) $P(err) = \dfrac{(2^{\ell}-1)\, e^{-1/2(S/N)^2}}{\sqrt{2\pi}\;\; S/N}$

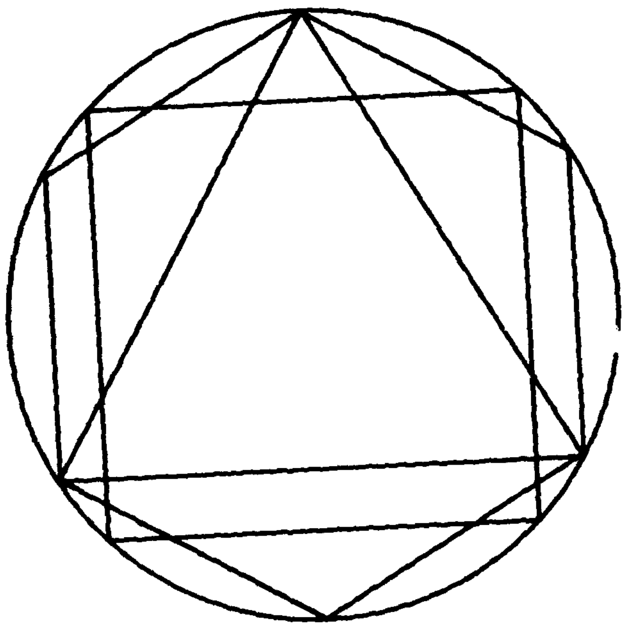
  FROM PROBABILITY OF A NOISE SPIKE IN A NOISE-ONLY SLOT EXCEEDING THE SIGNAL LEVEL

- BUT - (a) COMPARING SIGNAL + NOISE TO NOISE, AND (b) "NOISE" IS FLUCTUATIONS DUE TO AVERAGE BACKGROUND SHOT-NOISE

  ⇒ EFFECTIVE $\sqrt{2}$ DECREASE IN SIGNAL + NOISE LEVEL MUST BE ACCOMODATED

- NEW EXPRESSION: (BOUND) $P(err) = \dfrac{(2^{\ell}-1)}{\sqrt{2\pi}} \; \dfrac{e^{-1/2(S/\sqrt{2}\,N)^2}}{(S/\sqrt{2}\,N)}$

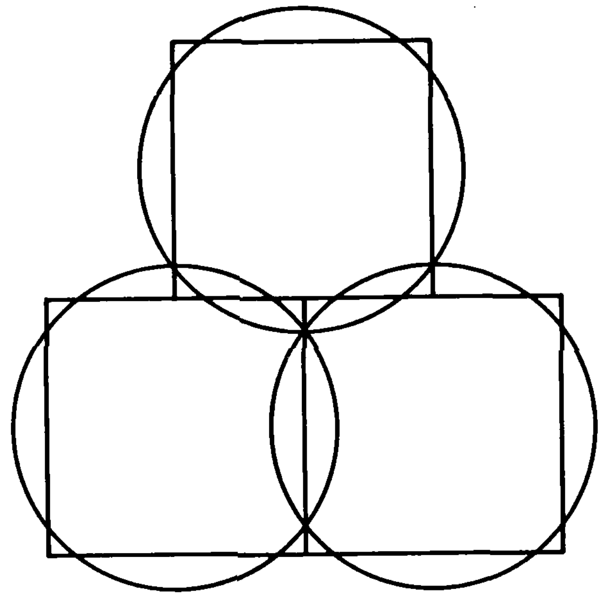
SPOT SHAPE, SPOT PATTERN CONSIDERATIONS



SCAN EFFICIENCY

EQUILATERAL TRIANGLE	$\frac{3\sqrt{3}}{4\pi}$	41.35%
SQUARE IN CIRCLE	$\frac{2}{\pi}$	63.66%
HEXAGON IN CIRCLE	$\frac{3\sqrt{3}}{\pi 2}$	82.7%
STAGGERED SQUARE PATTERN	$\frac{1}{\pi(5/8)^2}$	81.5%

STAGGERED SQUARE PATTERN



- SELECTED APPROACH - ESCAPE PROBABILITY IMPACT TBD

HIGHER ORBIT ANALYSIS

- ANAMORPHIC CORRECTION IMPACT
- RANDOM SCAN "COST"
- CORRECTION TO REQUIRED SNR
- SPOT SHAPE, SPOT PATTERN CONSIDERATIONS
- ADDITIONAL DCM RUNS

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ADDITIONAL DCM RUNS

DCM LOG

#	
DATE	
PROPAGATION MODEL:	CLOUDS
	WATER
	BLUE-SKY
	BIOLUMINESCENCE
DATA BASES:	CLOUDS
	WATER
	BIOLUMINESCENCE
	SUN LOCATION
MESSAGE TYPE	
BITS PER PULSE	
ENERGY PER PULSE	
PULSE REPETITION FREQUENCY	
OPTICAL FILTER BANDPASS	
OPTICS TRANSMISSION: TRANSMITTER/RECEIVER	
DETECTOR QUANTUM EFFICIENCY	
WAVELENGTH	
RECEIVER APERTURE DIAMETER	
RECEIVER FIELD-OF-VIEW/POINTING STRATEGY	
OVERLAP STRATEGY	
SLOTWIDTH	
INTER FRAME DEADTIME	
INTER MESSAGE DEADTIME	
REMOTE SENSING STRATEGY	
SATELLITE CHARACTERISTICS:	NUMBER
	ORBITS
	LOCATION
KEY POINT EXPLORED	

$S/N)_{REQ} =$

DCM RUN NO. 2: RESULTS

MESSAGE LENGTH	DEPTH IN TYPE III WATER	DOWNLINK AVAILABILITY
EAM	FULL	0.78
EAM	75%	0.88
EAM	50%	0.9
16 BIT	FULL	0.86
16 BIT	75%	0.97
16 BIT	50%	0.99

GTE Systems

DCM RUN NO. 3: RESULTS

MESSAGE LENGTH	DEPTH IN TYPE III WATER	DOWNLINK AVAILABILITY
EAM	FULL	0.48
EAM	75%	0.53
EAM	50%	0.57
16 BIT	FULL	0.64
16 BIT	75%	0.72
16 BIT	50%	0.81

DCM RUN NO. 4: RESULTS

LASER POWER (WATTS)	AREA	DOWNLINK AVAILABILITY
50	FULL	0.48
50	HALF+	0.73
200	FULL	0.61
200	HALF+	0.85

+HALF AREA BELOW 34^{0} N

DCM RUN NO. 5: RESULTS

AREA	AVAILABILITY	INCREASE RELATIVE TO #4
FULL	0.5016	0.0216
HALF	0.6521	0.0421

DCM RUN NO. 6: CONSTANT SPOT AREA IMPACT: GREEN GEOSTAT

- $A_{SPOT} = \frac{\text{REQUIRED AREA}}{\text{NUMBER SPOTS}}$
- $\text{NUMBER SPOTS} = \frac{\text{TIME TO COVER AREA}}{\text{PER SPOT DWELL TIME}}$
- $A_{SPOT} = (345\ \text{km})^2 = 9.3\,(10^{10})\,\text{m}^2$

GTE SYLVANIA

DCM RUN NO. 6: RESULTS

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AREA	DOWNLINK AVAILABILITY	DECREASE RELATIVE TO #5
FULL	0.3192	0.1824
HALF+	0.415	0.2371

+ALSO USING 345 km SPOTS

DCM RUN NO. 7: RESULTS

DOWNLINK AVAILABILITY

AREA	#5	#6	#7
FULL	0.5016	0.3192	0.5178
HALF	0.6521	0.415	0.6731

- 10 dB IN SINGLE PULSE SNR PARAMETER COMPENSATED FOR

  A. NO REMOTE SENSOR

  AND B. CONSTANT SPOT AREA STRATEGY

SYSTEMS ANALYSIS

- NEAR EARTH ORBIT ANALYSIS
- CONTINUING HIGHER ORBIT ANALYSIS
- NAVY PROPAGATION MODEL REVISIONS AND RELATED TOPICS
- DEPTH NOMOGRAPH I

NAVY PROPAGATION MODEL REVISIONS AND RELATED ISSUES

- "RECENT" NOSC CHANGES TO THE PROPAGATION MODEL
- RECEIVER FIELD-OF-VIEW OPTIMIZATION
- ALTERNATE STRATEGY IF REMOTE SENSING IS NOT AVAILABLE

RECENT NOSC CHANGES TO THE PROPAGATION MODEL

- NUMEROUS MINOR CHANGES
- MAJOR CHANGES - CLEAR WEATHER WATER TRANSMISSION MODEL
  BIOLUMINESCENT STRENGTH
  K VALUES
- COMPARE OLD AND NEW MODELS, AND THE SYSTEM IMPACT

CLEAR WEATHER WATER TRANSMISSION MODEL

OLD MODEL

$$\tau_W = \prod_i \exp - (k_i D_i / \cos \phi_{SW})$$

NEW MODEL

$$\tau_W = \tau(\phi_{SW}) F(\phi_{SW})$$

$F(0^0) = 1$

$F(45^0) = 0.542$

DEPTH: < 30m: $\dfrac{\tau(\phi_{SW})}{\exp - \left(kD/\cos \phi_{SW}\right)}$

30-50m: SAME, FOR $\phi_{SW} \leq 30^0$

: $\left[e^{\frac{-(k-30)}{\cos \phi_{SW}}} \right] \left[e^{\frac{-kp(D-30)}{\cos \phi_{SW}}} \right]$

> 50m: $\left[e^{\frac{-(k-50)}{\cos \phi_{SW}}} \right] \left[e^{-kp(D-50)} \right]$

WATER TRANSMISSION MODEL II

$kp\ (m^{-1})$	WATER TYPE
0.033	IB
2/3 (0.063)	II
1/3 (0.116)	III

- SYSTEM IMPACT:
  - (a) ENHANCED AVAILABILITY
  - (b) NO RECEIVER POINTING AT DEPTH

BIOLUMINESCENCE

OLD MODEL	NEW MODEL
NO FOV DEPENDENCE	$(1 - \cos\theta_R)$ DEPENDENCE
$H_{BL} = 10^{-3} \frac{\text{WATTS}}{m^2 \text{SRAD}\mu m}$	$H_{BL} = 6.38\,(10^{-3}) \left\{ 1.067k + 0.033 \right\} \frac{\text{WATTS}}{m^2 \text{SRAD}\mu m}$

SYSTEM IMPACT:

k(m-1)	H_{BL}	ΔSNR FOR BIOLUMINESCENT LIMITED OPERATION
0.033	$4.35\,(10^{-4})$	1.5
0.067	$6.67\,(10^{-4})$	1.22
0.116	10^{-3}	1

- IMPROVED PERFORMANCE

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K VALUES

OLD MODEL

k $\longrightarrow$ 2/3 (SURFACE k) BELOW THERMOCLINE

NEW MODEL

WATER TYPE	k BELOW THERMOCLINE
IB	AS ABOVE THERMOCLINE
II	2/3 OF k ABOVE
III	1/3 OF k ABOVE

- SYSTEM IMPACT - ENHANCED PERFORMANCE

FIELD OF VIEW OPTIMIZATION

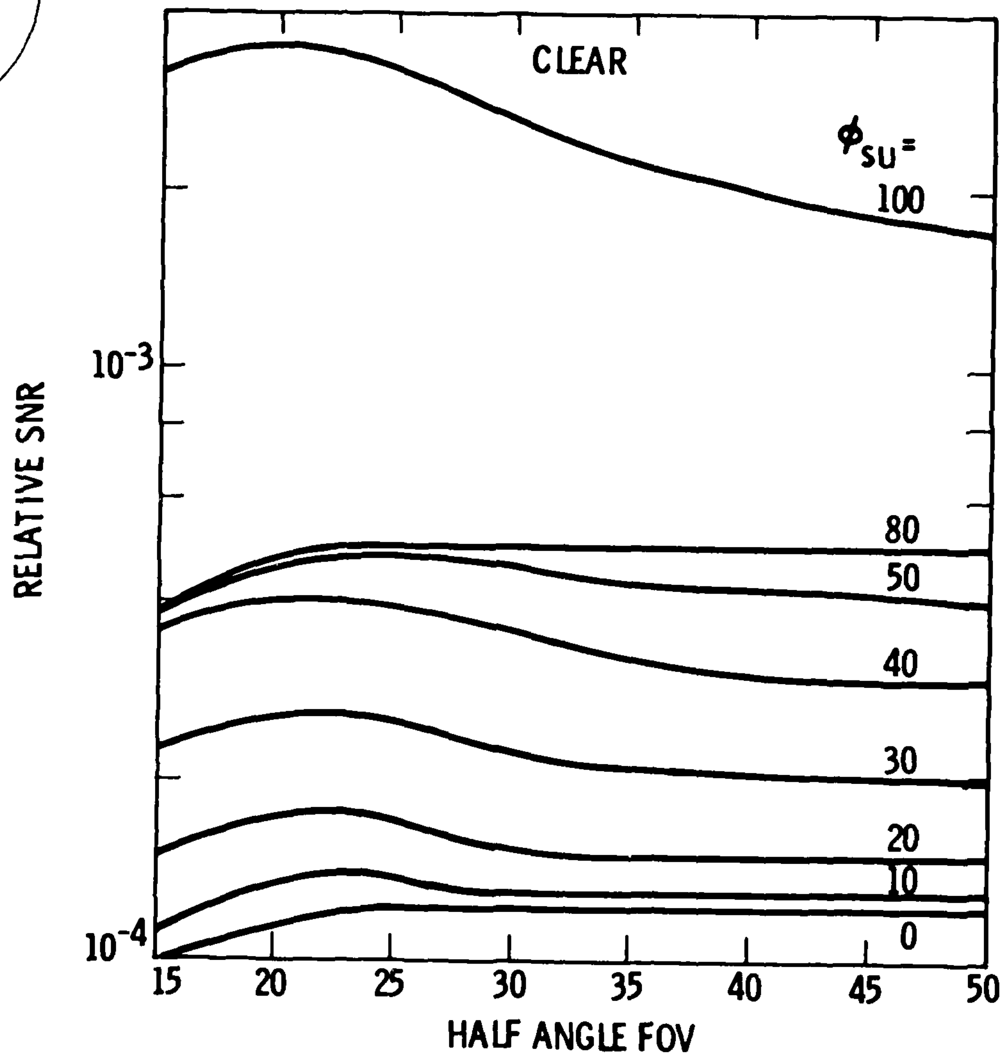
- BLUE SKY

$$f\left(\phi_0, \theta_p, \delta_{sky}\right) 2\pi\left(1-\cos\theta_R\right) \longrightarrow f\left(\phi_0, \theta_R, \delta_{sky}\right)$$

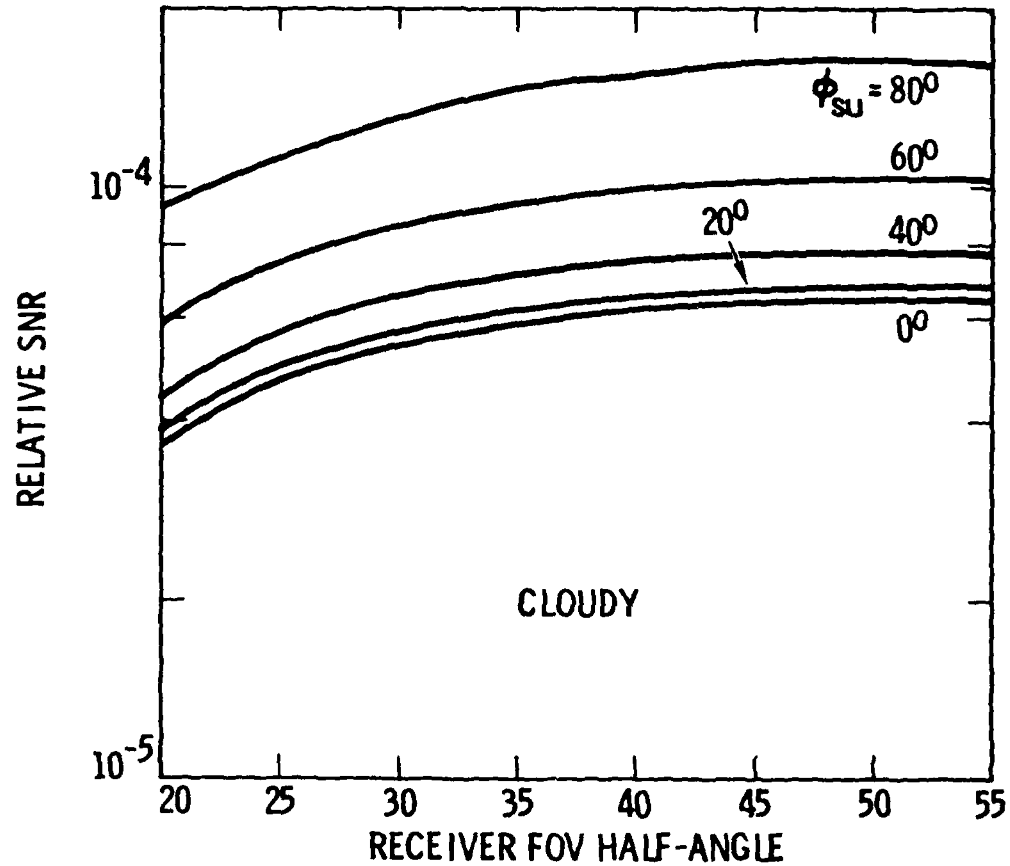
- BIOLUMINESCENCE

$$1 \longrightarrow \left(1-\cos\theta_R\right)$$

CLEAR WEATHER RESULT



CLOUDY RESULT



STRATEGY IN LIEU OF REMOTE SENSING

- EQUAL AREA SPOTS
- SPOT AREA DEPENDENT ON LONG-TERM KNOWLEDGE OF WATER AND CLOUD TYPE

$$N_{SP}(IB) + N_{SP}(II) + N_{SP}(III) = N_{SP}(TOTAL)$$

$$N_{SP}(IB) \cdot A_{IB} + N_{SP}(II)\ A_{II} + N_{SP}(III)\ A_{III} = A_{TOT}$$

PACIFIC

$$N_{SP}(IB)\ A_{IB} = 73\,(A_{ERE});\quad N_{SP}(II)\ A_{II} = 27\,(A_{ERE});\quad N_{SP}(III) = A_{III}\ 30\,(A_{ERE})$$

- DCM EXPERIENCE $\Longrightarrow$ A_{III} DOWN TO $(40\ km)^2$

  AND A_{IB} UP TO $(550\ km)^2$

SYSTEMS ANALYSIS

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- NEAR EARTH ORBIT ANALYSIS
- CONTINUING HIGHER ORBIT ANALYSIS
- NAVY PROPAGATION MODEL REVISIONS AND RELATED TOPICS
- DEPTH NOMOGRAPH I

Sylvania Systems Group
Western Division

NOMOGRAPH I DEVELOPMENT

- $$\frac{S}{N} = A \left[\frac{E_p^2 \eta d^2 \gamma_R}{B_{OPT}}\right]^{1/2} \frac{\tau_{SIG} \tau_W^s f_{SIG}}{\left[H_{s\lambda} \tau_{SUN} \tau_W^{su} f_{SUN} + L_B \tau_{SKY} \tau_W^{sk} f_{SKY} \Omega_R + L_{BL}\right]^{1/2}}$$

- NEGLECT DEPTH DEPENDENCE OF ALL f_i

- ONE BACKGROUND DOMINATES

SUN-LIMITED $$\frac{\tau_W^s}{\left[\tau_W^{su}\right]^{1/2}} = \left[\frac{E_p^2 \eta d^2 \gamma_R}{B_{OPT}}\right]^{-1/2} A_1$$

SKY-LIMITED $$\frac{\tau_W^s}{\left[\tau_W^{sky}\right]^{1/2}} = \left[\frac{E_p^2 \eta d^2 \gamma_R}{B_{OPT}}\right]^{-1/2} A_2$$

BIO-LIMITED $$\tau_W^s = \left[\frac{E_p^2 \eta d^2 \gamma_R}{B_{OPT}}\right]^{-1/2} A_3$$

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NOMOGRAPH I DEVELOPMENT (CONT'D)

- τ_W ARE CLOUD THICKNESS DEPENDENT TOO
- DEFINE F_i:

$F_1 = \cos \phi_s^W$	THIN CLOUD/BIO
$F_2 = \dfrac{2 \cos \phi_{su}^W \cos \phi_s^W}{2 \cos \phi_{su}^W - \cos \phi_s^W}$	THIN CLOUD/SUN
$F_3 = \dfrac{2 \cos \phi_s^W}{2 - \cos \phi_s^W}$	THIN CLOUD/SKY
$F_4 = 2$	THICK CLOUD/SUN OR SKY
$F_5 = 1$	THICK COULD/BIO

$$\Rightarrow \exp - \left(\frac{kD}{F_i}\right) = A_j \left[\frac{E_p^2 \eta d^2 \gamma_R}{B_{OPT}}\right]^{-1/2}$$

NOMOGRAPH I DEVELOPMENT (CONT'D)

- NORMALIZE TO REMOVE ALL Aj

$$\Rightarrow \exp - \left[\frac{k(\Delta D)}{F_i} \right] = \left[\frac{\overline{E_p^2}\ \overline{\eta}\ \overline{d^2}\ \overline{\gamma_R}}{\overline{B}_{OPT}} \right]^{-1/2}$$

- $k(\Delta D) = F_i\left(\phi_s^w, \phi_{su}^w\right) G\left(\overline{B}_{OPT}, \overline{E}_p, \overline{\eta}, \overline{d}, \overline{\gamma}_R\right)$

FOR

$$G = \ln \overline{E}_p + \ln \overline{d} - \frac{1}{2} \ln \overline{B}_{OPT} + \frac{1}{2} \ln \overline{\gamma}_R + \frac{1}{2} \ln \overline{\eta}$$

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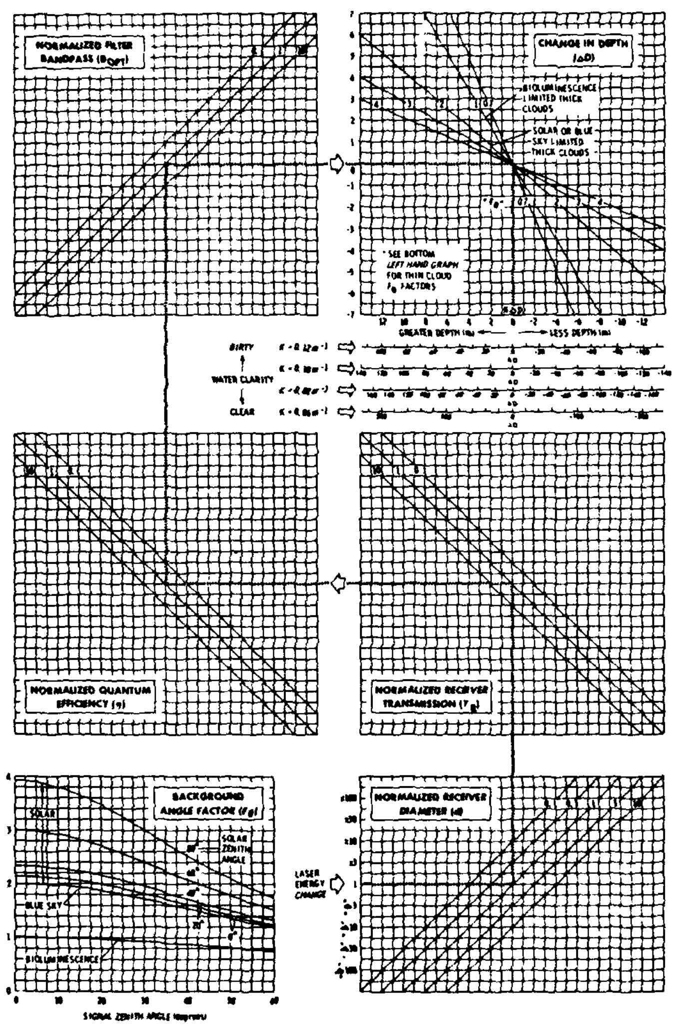
NOMOGRAPH I



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ASSUMPTIONS IN S/C SIZING

	LOW-EARTH	HIGH-EARTH
PRIME POWER	25 kW	25 kW
EFFICIENCY	1%	1%
ORBIT INCLINATION	TBD	60^0
LIFE	5 YEARS	5 YEARS
SUN ACTIVITY	MAX	MAX
LAUNCH VEHICLE	SHUTTLE OR FREE-FLYER →	
DRAG COEFFICIENT	2	N/A

GTE | Systems

CORRECTION TO REQUIRED SIGNAL-TO-NOISE RATIO

- PREVIOUS EXPRESSION: (BOUND) $P(err) = \dfrac{(2^{\ell}-1)\, e^{-1/2 (S/N)^2}}{\sqrt{2\pi}\;\; S/N}$

  FROM PROBABILITY OF A NOISE SPIKE IN A NOISE-ONLY SLOT EXCEEDING THE SIGNAL LEVEL

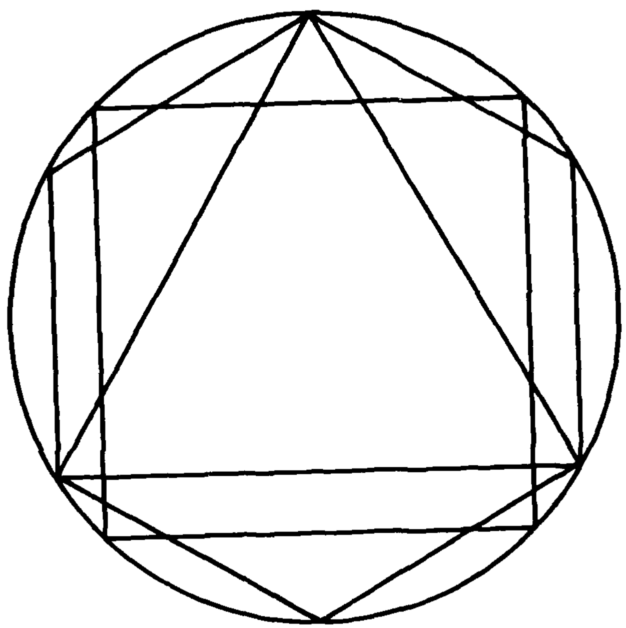
- BUT - (a) COMPARING SIGNAL + NOISE TO NOISE, AND (b) "NOISE" IS FLUCTUATIONS DUE TO AVERAGE BACKGROUND SHOT-NOISE

  $\Rightarrow$ EFFECTIVE $\sqrt{2}$ DECREASE IN SIGNAL + NOISE LEVEL MUST BE ACCOMODATED

- NEW EXPRESSION: (BOUND) $P(err) = \dfrac{(2^{\ell}-1)}{\sqrt{2\pi}} \;\; \dfrac{e^{-1/2 (S/\sqrt{2}\, N)^2}}{(S/\sqrt{2}\, N)}$

GTE Systems

SPOT SHAPE, SPOT PATTERN CONSIDERATIONS



SCAN EFFICIENCY

EQUILATERAL TRIANGLE	$\frac{3\sqrt{3}}{4\pi}$	41.35%
SQUARE IN CIRCLE	$\frac{2}{\pi}$	63.66%
HEXAGON IN CIRCLE	$\frac{3\sqrt{3}}{\pi 2}$	82.7%
STAGGERED SQUARE PATTERN	$\frac{1}{\pi(5/8)^2}$	81.5%

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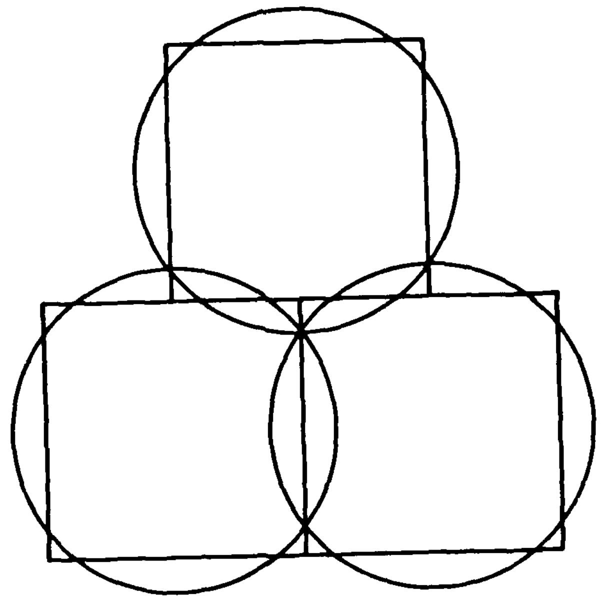
STAGGERED SQUARE PATTERN



- SELECTED APPROACH - ESCAPE PROBABILITY IMPACT TBD

HIGHER ORBIT ANALYSIS

- ANAMORPHIC CORRECTION IMPACT
- RANDOM SCAN "COST"
- CORRECTION TO REQUIRED SNR
- SPOT SHAPE, SPOT PATTERN CONSIDERATIONS
- ADDITIONAL DCM RUNS

ADDITIONAL DCM RUNS

DCM LOG

#	
DATE	
PROPAGATION MODEL:	CLOUDS
	WATER
	BLUE-SKY
	BIOLUMINESCENCE
DATA BASES:	CLOUDS
	WATER
	BIOLUMINESCENCE
	SUN LOCATION
MESSAGE TYPE	
BITS PER PULSE	
ENERGY PER PULSE	
PULSE REPETITION FREQUENCY	
OPTICAL FILTER BANDPASS	
OPTICS TRANSMISSION: TRANSMITTER/RECEIVER	
DETECTOR QUANTUM EFFICIENCY	
WAVELENGTH	
RECEIVER APERTURE DIAMETER	
RECEIVER FIELD-OF-VIEW/POINTING STRATEGY	
OVERLAP STRATEGY	
SLOTWIDTH	
INTER FRAME DEADTIME	
INTER MESSAGE DEADTIME	
REMOTE SENSING STRATEGY	
SATELLITE CHARACTERISTICS:	NUMBER
	ORBITS
	LOCATION
KEY POINT EXPLORED	

$S/N)_{REQ} =$

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DCM RUN NO. 2: RESULTS

MESSAGE LENGTH	DEPTH IN TYPE III WATER	DOWNLINK AVAILABILITY
EAM	FULL	0.78
EAM	75%	0.88
EAM	50%	0.9
16 BIT	FULL	0.86
16 BIT	75%	0.97
16 BIT	50%	0.99

DCM RUN NO. 3: RESULTS

MESSAGE LENGTH	DEPTH IN TYPE III WATER	DOWNLINK AVAILABILITY
EAM	FULL	0.48
EAM	75%	0.53
EAM	50%	0.57
16 BIT	FULL	0.64
16 BIT	75%	0.72
16 BIT	50%	0.81

DCM RUN NO. 4: RESULTS

LASER POWER (WATTS)	AREA	DOWNLINK AVAILABILITY
50	FULL	0.48
50	HALF+	0.73
200	FULL	0.61
200	HALF+	0.85

+HALF AREA BELOW 34^{0} N

DCM RUN NO. 5: RESULTS

AREA	AVAILABILITY	INCREASE RELATIVE TO #4
FULL	0.5016	0.0216
HALF	0.6521	0.0421

CORRECTION TO REQUIRED SIGNAL-TO-NOISE RATIO

- PREVIOUS EXPRESSION: $P(\text{err}) = \dfrac{(2^{\ell}-1)\, e^{-1/2\,(S/N)^2}}{\sqrt{2\pi}\;\; S/N}$
  (BOUND)

  FROM PROBABILITY OF A NOISE SPIKE IN A NOISE-ONLY SLOT EXCEEDING THE SIGNAL LEVEL

- BUT - (a) COMPARING SIGNAL + NOISE TO NOISE, AND (b) "NOISE" IS FLUCTUATIONS DUE TO AVERAGE BACKGROUND SHOT-NOISE

  $\Rightarrow$ EFFECTIVE $\sqrt{2}$ DECREASE IN SIGNAL + NOISE LEVEL MUST BE ACCOMODATED

- NEW EXPRESSION: $P(\text{err}) = \dfrac{(2^{\ell}-1)}{\sqrt{2\pi}} \; \dfrac{e^{-1/2\,(S/\sqrt{2}\,N)^2}}{(S/\sqrt{2}\,N)}$
  (BOUND)

DATE
FILMED

-8